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FLIGHT CAMERA STUDY OF ROCKET EXHAUST RF ATTENUATION ON THE NASA SCOUT

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FLIGHT CAMERA STUDY OF ROCKET EXHAUST

RF ATTENUATION ON THE NASA SCOUT

By Duncan E. McIver, Jr.*

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ABSTRACT

Results of NASA Langley Research Center's investigation of RF signal attenuation due to the exhaust of the Scout booster will be given. The present investigation is an extension of the rocket flame attenuation study as reported in NASA TM X 529.

A film from a recoverable flight camera, which reveals unique details of the exhaust during a period of attenuation will be shown. The film, which was obtained during a midnight launch, shows specific changes in the exhaust free jet characteristics which coincide with the onset of RF attenuation. Possible reasons for the changes and resulting effects on RF signal transmission will be discussed.

* Aerospace Technologist

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By Duncan E. McIver, Jr.*

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INTRODUCTION

When the first Scout, NASA's large solid propellant research booster, shown on the launcher in figure 1, was launched from Wallops Island, Virginia, in July 1960, a significant interference of telemetry signals was observed. During the burning of the second stage motor, in the altitude range from 180,000 feet to 260,000 feet, the launch site tracking station recorded a signal attenuation of about 20 db. This was one of the first known occurences of severe attenuation due to a solid propellant rocket motor.

Unexpectedly, each time the hydrogen peroxide attitude control jets, which are located at the base of the second stage motor, were actuated, this attenuation was completely eliminated. Details of this unique attenuation phenomenon are reported in reference 1, a NASA technical memorandum by Sims and Jones of the Langley Center.

The subsequent launches of the Scout have given Langley Research Center an opportunity to conduct a continuing study of this unusual exhaust phenomenon. The most recent effort was to fly a recoverable camera on Scout vehicle number 8 to photograph the exhaust of the second stage motor during the period of attenuation.

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The recovered film reveals the existence of a bright ring which forms on the periphery of the exhaust at the onset of attenuation. A portion of this ring disappears each time that the control jets are actuated, and simultaneously, telemetry attenuation is eliminated.

This presentation will briefly review details of the Scout attenuation phenomenon reported in reference 1, describe the camera experiment flown on Scout vehicle number 8, and discuss a possible explanation for the bright ring observed by the camera and the associated attenuation observed on the ground.

THE SCOUT ATTENUATION-RECOVERY EFFECT

Figure 2 is a representation of the results as reported in reference 1. The top curve shows the chamber pressure of the second stage motor, which ignited at 130,000 feet. Attenuation of telemetry signals began at about 197,000 feet and continued until motor tail off at 258,000 feet. The attenuation was relieved each time the hydrogen peroxide control jets were actuated. The control jet sequence is indicated by the lower curve. The amount of attenuation was about twenty (20) db and this was for VHF telemetry signals only. A 5 KMC tracking radar showed only minor (1 or 2 db) interference during this period.

Figure 3 shows the top three stages of the Scout vehicle as they would appear during the attenuation period. The antennas were located some thirty to forty feet away from the exhaust. There were two sets of antennas, indicated here as forward and aft, which were about five feet apart. These antennas were spikes protruding from the vehicle. The power to the antennas was about ten (10) watts.

The attitude control jets were located near the exhaust and generated thrust by the decomposition of hydrogen peroxide. The decomposition products, 60% water vapor and 40% oxygen, were injected into the flow field at a rate of 3.5 pounds/sec. The mass flow of the main exhaust by comparison was about 240 pounds/sec. There are four independent jets and either causes complete recovery when actuated.

Two stations recorded signal strength during the data period, Wallops Island launch site at 4^{0} look angle and the Langley Research Center at 54^{0} look angle. At the Langley site, signals from the forward antenna showed the reverse of that observed at Wallops. The signal was enhanced by about 5 db during the data period and returned to normal when the control jets fired. Results from later Scout launches indicate that Langley generally sees attenuation from the aft antenna.

The conclusion reached in reference 1 was that the attenuation was caused by an effect on the surface of the exhaust, probably afterburning, and that recovery occurred when the decomposition products of the control jet cooled the exhaust-flow field interface. One approach to substantiate these conclusions was to fly a camera to film the exhaust region during this period. This was done on a recent Scout launching from NASA Wallops Station.

THE CAMERA EXPERIMENT

The camera was a modified gun sight type, mounted in a recoverable pod and attached to the top of the second stage motor as shown in

Figure 4. This vehicle, Scout #8, was launched shortly after midnight on March 1, 1962. The camera pod was positioned over the control jet that fires most frequently. The semi-circle at the bottom of the vehicle indicates the camera field of view. A neutral density filter was placed over a portion of the lens to allow some latitude in exposure and is represented by the shaded area. The image of the exhaust, however, is most clear in the unfiltered quadrant. The film shows the second stage exhaust free jet expanding into this quadrant as the Scout rises in altitude. Two of the control jets can be seen to fire intermittently along the edges of the quadrant.

The camera was turned on at minus five seconds and it ran to plus 120 seconds, covering the burning of the first and second stage motors. At 120 seconds the pod was ejected and allowed to follow a ballistic trajectory to about 20,000' altitude where a parachute was deployed. A homing radio beacon, actuated on water impact, directed the recovery team and recovery was accomplished within three and one half hours after launch. The pod impact was about 500 miles from the launch site.

FILM SEQUENCE

The recovered film shows some significant changes in the exhaust during the RF attenuation period. Figure 5 lists the sequence of important events.

1. Lift off - The first stage motor illuminates the Wallops launch site as it leaves.

2. First stage operation - The first stage motor can be seen burning and occasionally the image brightens as the vehicle passes through clouds.

3. Second stage ignition - For clarity we have triple framed the original film at this point to induce slow motion. The second stage ignites at about 130,000 feet.

4. Formation of a bright ring - At 181,000 feet a distinct bright ring forms on the periphery of the exhaust image. Its formation coincides exactly with the onset of telemetry signal attenuation.

5. Control Jet Operation - Occasionally a portion of the bright ring disappears as the control jets are actuated. This disappearance coincides with the recovery from attenuation.

6. Second stage tail off - Just prior to burn out of the second stage, the ring fades as do the attenuation effects. This occurs at about 225,000 feet.

FILM

(The film will be shown at this time. The running time is just under three minutes.)

RESULTS

The film, it is believed, provides substantial evidence to support the preliminary conclusions about the exhaust effect. The analysis of the film and a discussion of the present view of this attenuation effect will now be presented.

Figure 6 shows several pertinent frames from the film with associated trajectory information. The first two, which are consecutive, show the formation of the ring which occurred between two frames or within 0.07 seconds. The altitude at this time was 181,000 feet and the velocity was 5820 feet per second. The pronounced attenuation effect occurs simultaneously with the formation of this ring.

The lower three frames which are also consecutive, show the result of the firing of a single attitude control jet. It appears that about a ninety (90) degree segment of the ring is removed. This disappearance of a portion of the ring corresponds to the VHF signal recovery from attenuation. These frames are later in the attenuation period at an altitude of 215,000 feet with a velocity of 7760 feet per second.

As expected, the radius of the exhaust and the ring grow larger as the Scout reaches higher altitudes. The ring becomes slightly thinner as its radius grows. However, it retains an angular thickness of about 5^{o} throughout the attenuation period.

The level of attenuation and the nature of the recovery was very similar to that of the first Scout discussed in reference 1.

DISCUSSION

In discussing the creation of the ring on the film and the attenuation effects on telemetry signals, it is necessary to examine the flow field around the Scout vehicle. Reference 2 by Falanga, Hinson and Crawford of the Langley Research Center, a study of the effect of jet plumes on vehicle stability, indicates that the exhaust gases from the rocket motor of a vehicle in the altitudes of interest to the Scout second stage expand to form a large free jet or plume as the ratio of jet exit pressure to ambient pressure becomes large. The presence of this large jet causes the free stream flow to deflect; this deflection causes a shock wave which interacts with the boundary layer of the vehicle. Because of the interaction, flow separation can occur on the vehicle surface. The separated flow re-attaches to the exhaust at some distance from the vehicle and creates on the exhaust surface a turbulent mixing region which is believed to be the source of attenuation effects. This mixing region has been discussed by Boynton of Convair in reference 3.

Figure 7, which is based on information from references 2 and 3, summarizes the principle features of the exhaust free jet and vehicle flow field interaction for the Scout during the period of attenuation. The primary characteristics of the flow field to note are the following: (1) The large expanded exhaust free jet and the resulting separated flow region; (2) the mixing region, which begins at the attachment of the separated boundary, downstream of the nozzle, and (3) the shock waves in the flow field such as the bow shock, the shock off the separated region, the shock off the jet boundary, and the internal jet shock.

In the mixing region, gases from the fuel rich exhaust, principally hydrogen and carbon monoxide, combine with air from the supersonic flow field, which has been heated on passage through the free stream shocks and air from the separated flow region and afterburning occurs. This process has been discussed by Boynton in reference 3 and by Eugene Love of the Langley Center in reference 4. Associated with this afterburning are thermal and chemi-ionization processes which create a sheath of electrons on the surface of the jet causing the observed attenuation. Since it is doubtful that the temperature is sufficiently high to explain the attenuation in terms of thermal ionization alone, the chemi-ionization process is probably the major contributor of electrons. This latter point is supported by Love in reference 4 and by Calcote in reference 5.

When the control jets are actuated, the decomposition products water vapor and oxygen, are injected into the separated and mixing regions. Their presence quenches the afterburning process either by cooling the mixing region or by acting as a shield between the flow field air and the exhaust gases. The quenching is very rapid, occurring within 1/100th of a second. The return of the attenuation is slower, within about 3/10ths of a second and is probably due in part to gases trapped in the separation region.

It is believed then that the bright ring appearing in the film is the result of afterburning in a mixing region on the surface of the exhaust free jet, and that chemi-ionization processes in this mixing region are the cause of the observed RF attenuation. The intermittent disappearance of a portion of ring in the film is the result of the decomposition products of the control jets quenching the afterburning and relieving the attenuation effects.

It was originally hoped that we had uncovered a general solution to rocket exhaust-RF attenuation problems; however, if our conclusions are correct, this type solution would only be practical when afterburning is the major source of electrons in the exhaust.

CONCLUDING REMARKS

The flight film of Scout Vehicle 8, which shows significant changes in the exhaust during the attenuation period, provides additional information to substantiate the explanation presented in reference 1 for the Scout rocket exhaust-RF attenuation effect. The cause of the attenuation appears to be afterburning and associated chemi-ionization on the surface of the exhaust and the relief of attenuation appears to be quenching of the afterburning by the exhaust products of the control jet, principally water vapor, by either cooling or acting as a shield between the heated flow field air and the fuel rich exhaust gases. The results of this investigation show that if afterburning is the prime source of ionization in the rocket exhaust, the attenuation effects can be eliminated by the injection of material such as water vapor into the burning region.

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(typed 9-14-62)

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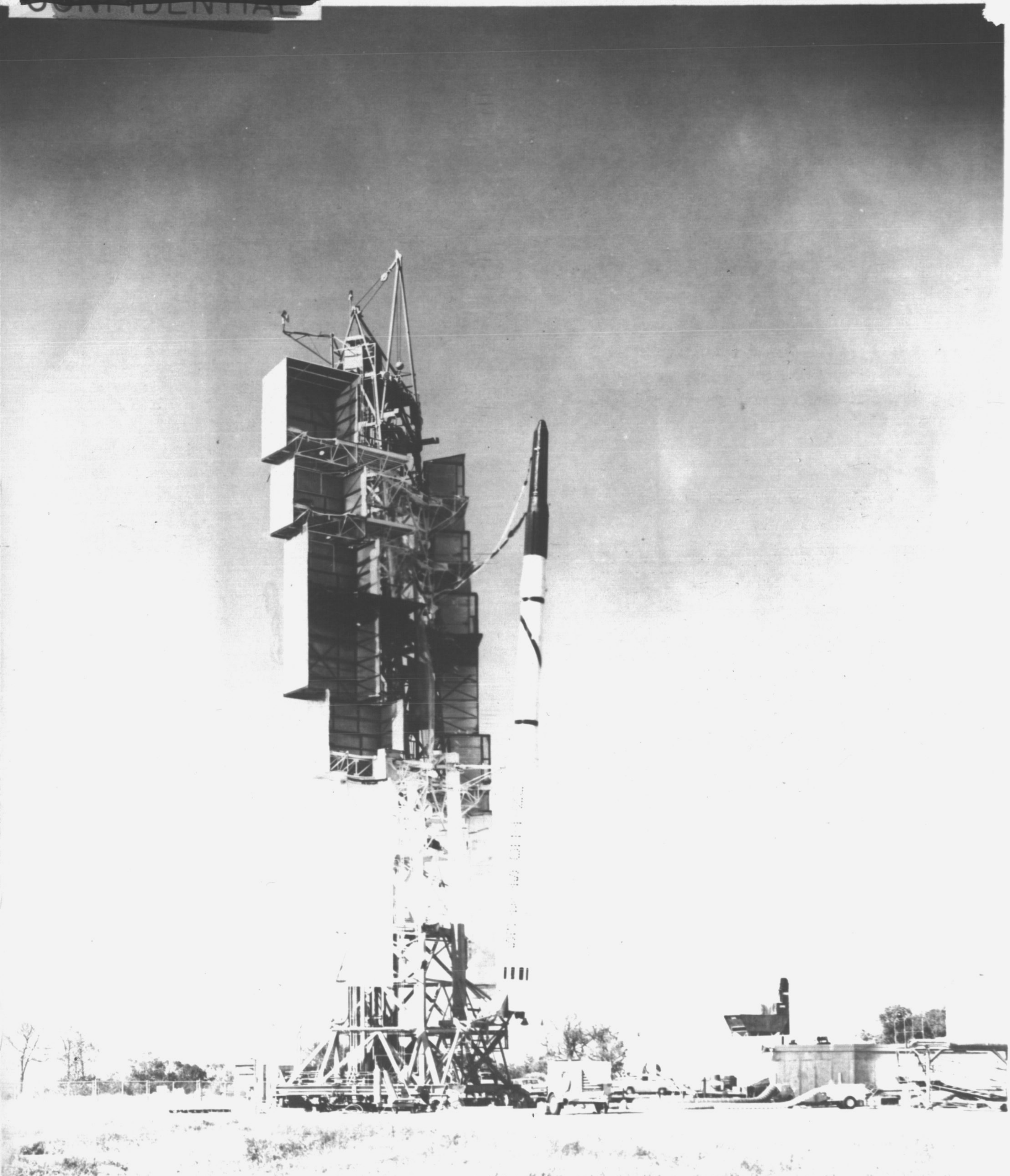
[redacted]



NASA
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Figure 1 The NASA Scout Vehicle

[redacted]

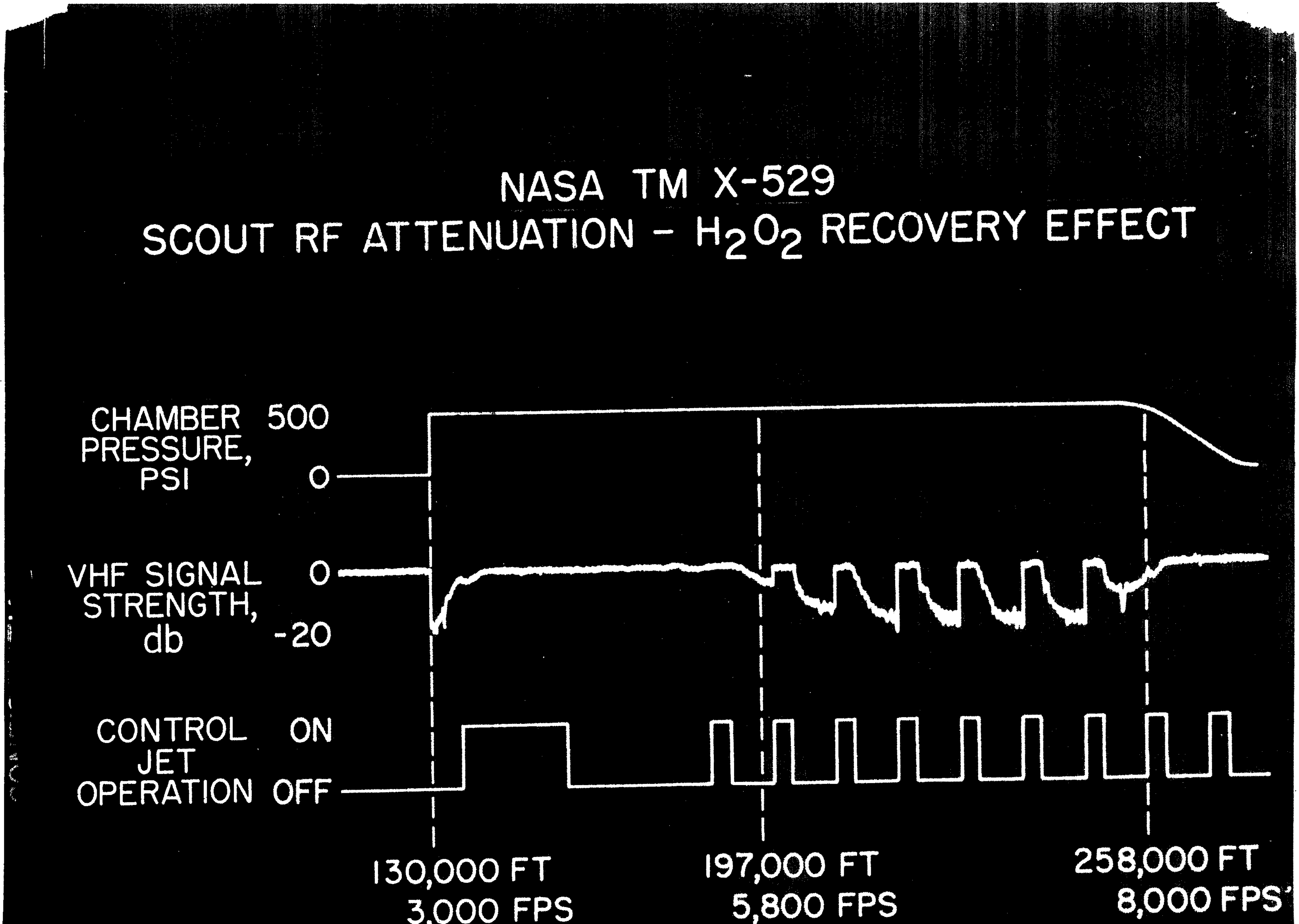
NASA TM X-529
SCOUT RF ATTENUATION - H_2O_2 RECOVERY EFFECT
CHAMBER PRESSURE, PSI
500
0
VHF SIGNAL STRENGTH, db
0
-20
CONTROL JET OPERATION
ON
OFF
130,000 FT
3,000 FPS
197,000 FT
5,800 FPS
258,000 FT
8,000 FPS

Figure 2

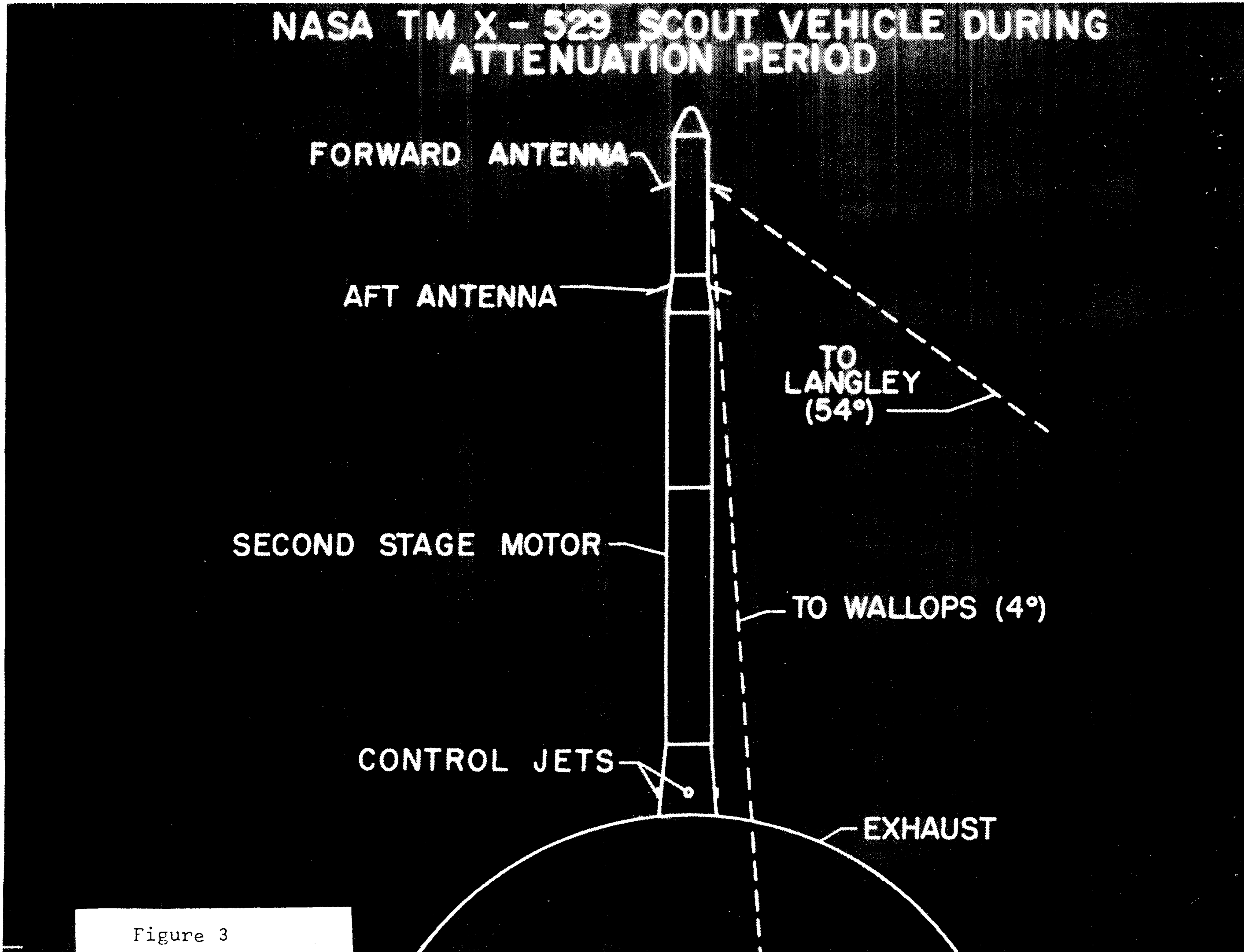
NASA TM X - 529 SCOUT VEHICLE DURING ATTENUATION PERIOD
FORWARD ANTENNA
AFT ANTENNA
TO LANGLEY (54°)
SECOND STAGE MOTOR
TO WALLOPS (4°)
CONTROL JETS
EXHAUST

Figure 3

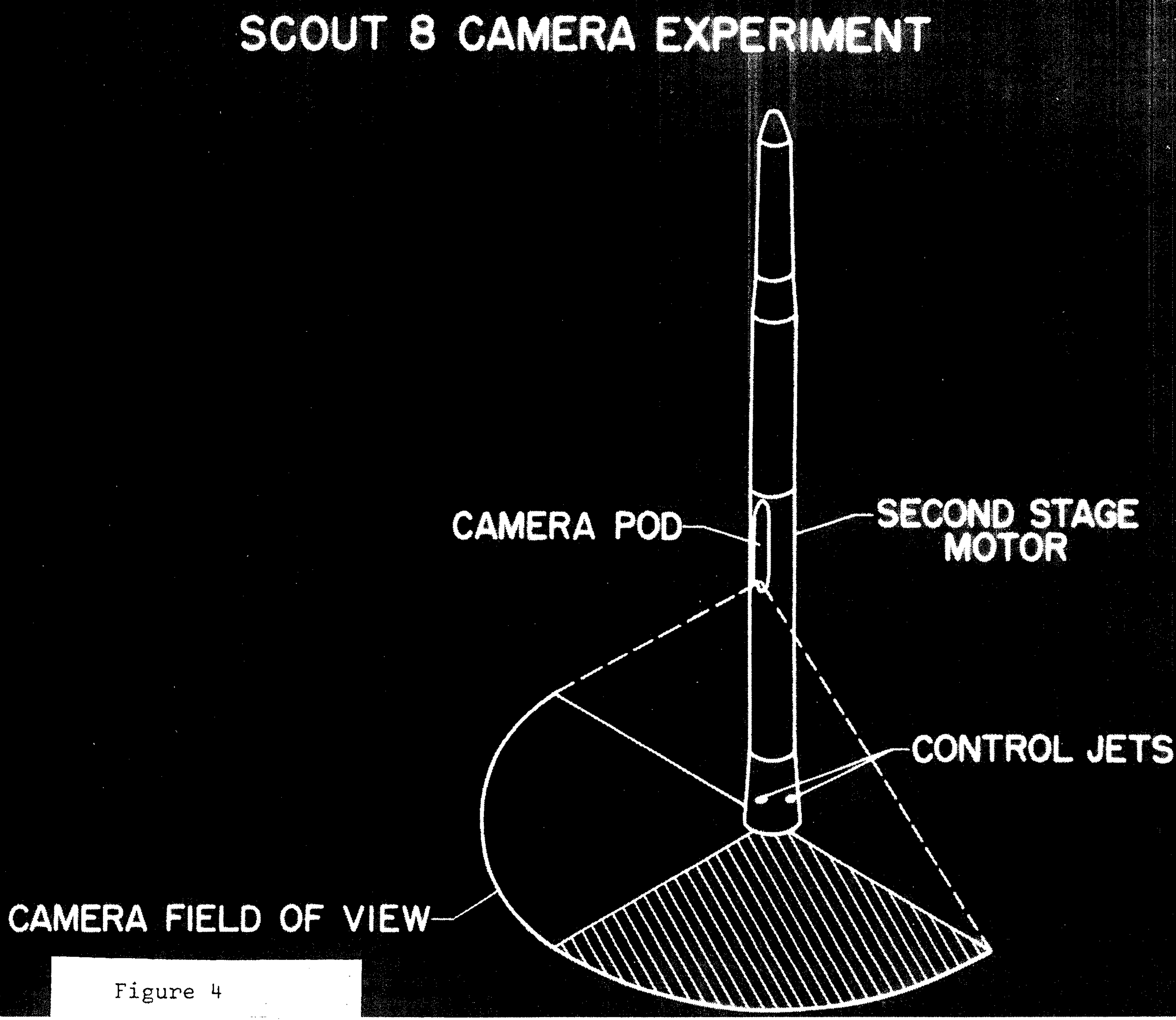
SCOUT 8 CAMERA EXPERIMENT
CAMERA POD
SECOND STAGE MOTOR
CONTROL JETS
CAMERA FIELD OF VIEW

Figure 4

SEQUENCE OF EVENTS – FLIGHT FILM OF NASA SCOUT 8

1. LIFT-OFF
2. FIRST STAGE OPERATION
3. SECOND STAGE IGNITION – 130,000 FEET (TRIPLE FRAMING BEGINS)
4. FORMATION OF BRIGHT RING – 181,000 FEET
5. CONTROL JET OPERATION
6. SECOND STAGE TAIL-OFF – 225,000 FEET

Figure 5

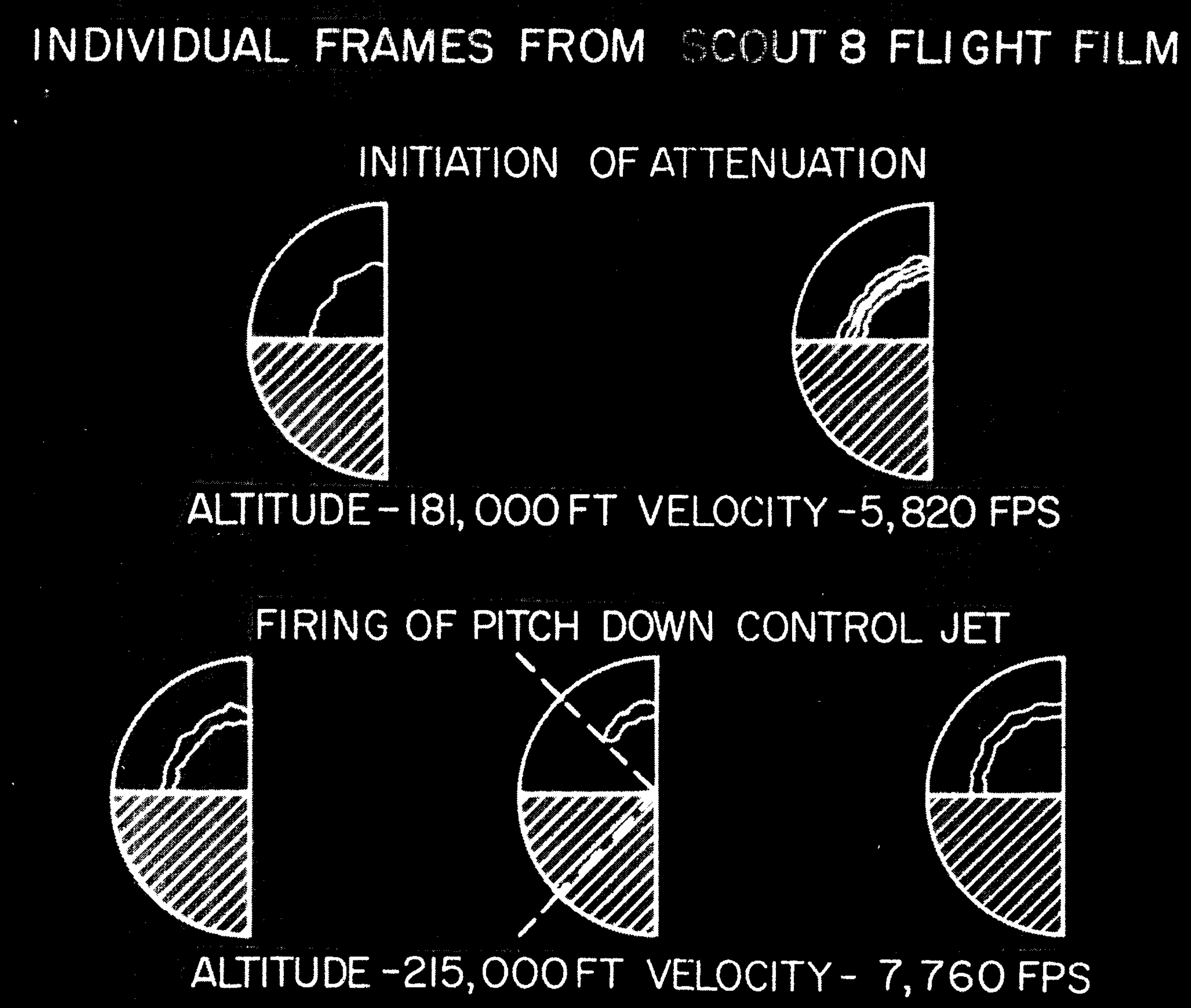
INDIVIDUAL FRAMES FROM SCOUT 8 FLIGHT FILM
INITIATION OF ATTENUATION
ALTITUDE - 181,000 FT VELOCITY - 5,820 FPS
FIRING OF PITCH DOWN CONTROL JET
ALTITUDE - 215,000 FT VELOCITY - 7,760 FPS

Figure 6

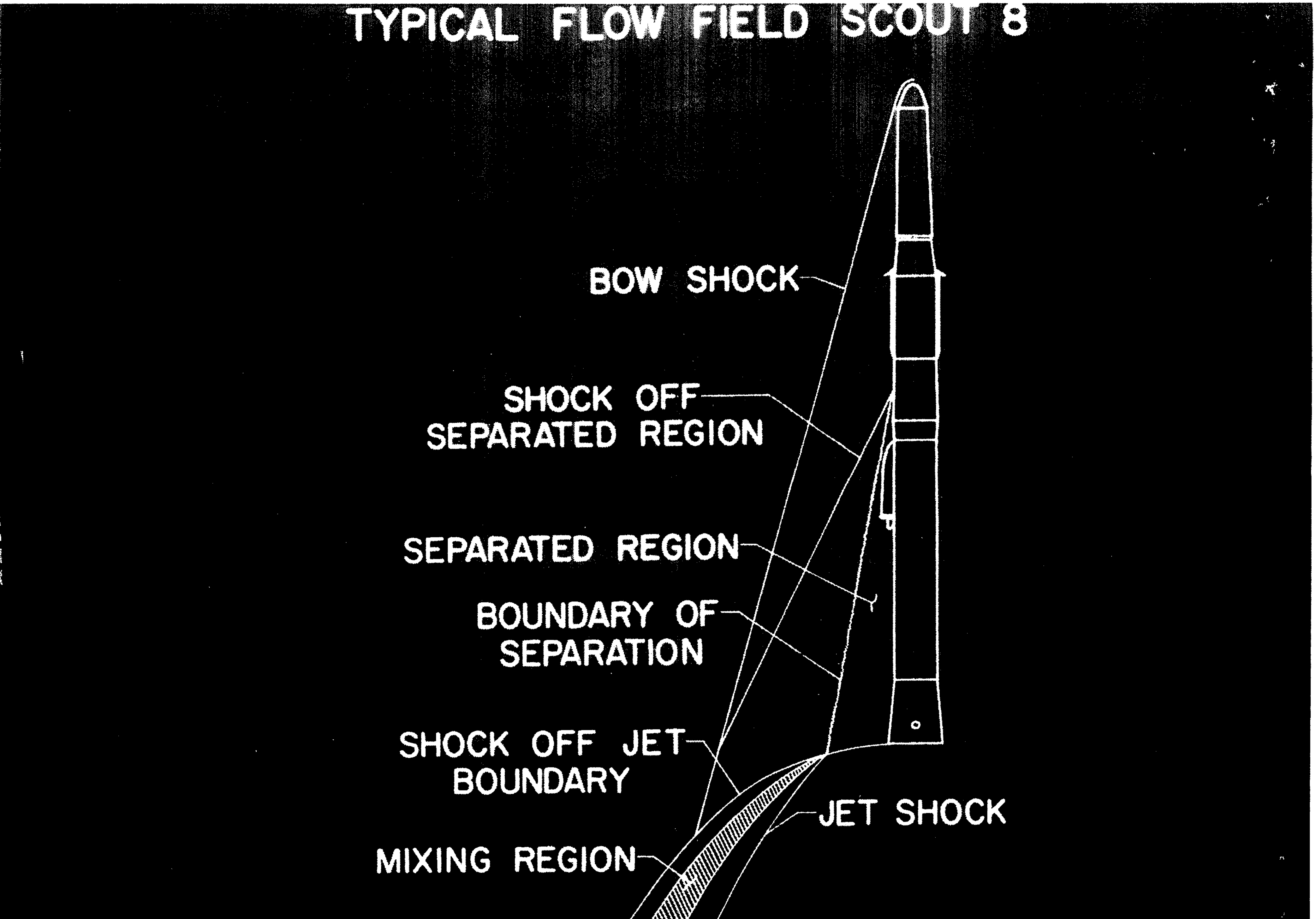
TYPICAL FLOW FIELD SCOUT 8
BOW SHOCK
SHOCK OFF SEPARATED REGION
SEPARATED REGION
BOUNDARY OF SEPARATION
SHOCK OFF JET BOUNDARY
JET SHOCK
MIXING REGION

Figure 7